2

GEOPHYSICAL SURVEYS
ISLAND OF MOLOKAI, HAWAII

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(Our Project #90007)

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1.0 INTRODUCTION

This report covers the results of geophysical surveys conducted by Blackhawk Geosciences, Inc. (BGI) for Alpha U.S.A., Inc. (Alpha) on the island of Molokai, Hawaii. The field work was performed between February 15 and March 4, 1990. Three separate geophysical surveys were used by BGI during this period. The geophysical surveys conducted and their individual objectives are as follows:

1. Seismic refraction surveys were utilized to map the depth to volcanic rocks and the seismic velocity distribution of the rock units in the area of Kamkaipo located in the southwest corner of the island. The seismic velocity distribution was subsequently correlated to mode and ease of excavation.

2. Gravity surveys were performed to outline intrusive (dense) bodies which may form a base to dike-impounded ground water and may be a source of vertical impounding dikes.

3. Time domain electromagnetic (TDEM) surveys were conducted to map the thickness of the fresh to brackish water lens and the location of dike-impounded ground water to better outline the geohydrologic system of Molokai's central aquifer area. In addition, work was performed to further delineate areas of relatively thick brackish water lenses identified in the previous TDEM survey in the western portion of Molokai.

The report is written in two parts. The first part consists of the TDEM and gravity surveys which address the mapping of ground water resources on Molokai, and the results of the seismic survey are contained in the second portion.

2.0 SURVEY DESIGN AND DATA ACQUISITION

2.1 TDEM

The TDEM survey was designed to outline the geohydrology of the central aquifer system. This was accomplished by mapping the depth to the saline water saturated volcanics and computing the thickness of the basal fresh water lens which underlies a large part of the area. In addition areas of high level dike impounded water in which saline water is not located at depth were identified. TDEM sounding locations were determined prior to the survey with Alpha's consulting hydrogeologist, Tom Nance. The sounding locations were modified during the survey based on initial results. These changes to the initial plan were made during consultation with Tom Nance and Bob Diffley of Alpha. The soundings were scattered throughout the central aquifer region. Fewer soundings were made within the higher elevation area which has been identified as a zone of high-level dike-impounded ground water. A greater number of soundings were located along the edge of the high-level dike-impounded ground water zone.

Soundings were also located in western Molokai to better outline thicker zones of the brackish water lens. The location of these soundings were determined primarily by access and the results of the previous TDEM survey.

2.1.1 Logistics

The geophysical survey was conducted by a two man crew from BGI. Two local hires were used to assist in the field work. The equipment was transported in the field utilizing a half-ton four-wheel drive pickup and a Jeep Wrangler.

The soundings were plotted on a U.S.G.S. 1:25,000 scale map and are shown on Figure 2-1. These locations were surveyed with compass and hip-chain from known locations such as road intersections.

A daily log of field activities is given in Table 2-1. The duration of TDEM field work was 17 days. Field work could not be done on March 1 due to heavy rains which made the dirt roads impassable. A total of 37 soundings were made during the field work. Twenty-nine of these soundings were in the area of the central aquifer. The remaining 8 soundings were made on western Molokai in areas where relatively thick brackish water zones were identified in the previous TDEM survey.

2.1.2 Data Acquisition

All soundings were made utilizing the Geonics EM-37 TDEM system with a DAS-54 data logger. Transmitter loop sizes utilized were 1,000 ft by 1,000 ft for 32 of the soundings; 1,500 ft by 1,500 ft for four soundings; and 1,500 ft by 1,000 ft for one sounding. The transmitter loop size was determined by (i) available space for laying out the loops, and (ii) required depth of exploration. The current in the loops was 19 amps. The transmitter-receiver array used consisted of center-loop soundings.

At the center of each transmitter loop the time derivative of the vertical magnetic field is measured at several different amplifier gains and opposite receiver polarities. Two different receiver coils with effective areas of 100 m^2 and 1000 m^2 were used. The base frequencies used were 3 Hz and 30 Hz. All data from the soundings were recorded on the DAS-54 data logger for later processing on a portable computer.

2.2 GRAVITY

2.2.1 Logistics

A total of 27 gravity stations were measured in a period of two field days. Two additional field days were required for an elevation survey for the gravity stations. One local hire was employed during the two days of elevation surveying. The locations of the gravity stations are shown on Figure 2-1.

A daily log of field activity is given in Table 2-2.

2.2.2 Data Acquisition

A line of gravity stations trending roughly northwest to southeast was acquired using station B-1 as a base station. The instrument used for gravity measurements was a LaCoste-Romberg Model G Gravimeter. Base station B-1 was occupied at the beginning of the survey and was reoccupied every few hours during the course of the survey, so that instrument drift could be accounted for in the data processing.

The elevation survey was run using a Lietz Set4 electronic total station. A point of known elevation indicated on the topographic map was tied to the surveyed line of gravity stations so that elevations above sea level could be computed for each gravity station.

Table 2-1. Daily Log of Field Activities (TDEM Survey)

Date (1990)	Activity
February 14	Mobilize from Denver, Colorado to Honolulu, Hawaii.
February 15	Mobilize from Honolulu to Molokai. Read loops CA1 and CA2. Site check loop locations in forest.
February 16	Read loops CA3, CA4 and CA5.
February 17	Read loops CA6, CA7 and CA8.
February 18	Read loops CA9, CA10 and CA11.
February 19	Read loops CA12 and CA13.
February 20	Read loops CA14 and CA15.
February 21	Read loops CA16, CA17 and CA18.
February 22	Read Loops CA19, CA20 and CA21.
February 23	Read loops CA22, CA23 and CA24.
February 24	Read loop CA25.
February 25	Read loops CA26 and CA27.
February 26	Read loop CA28.
February 27	Read loops CA29 and CA30.
February 28	Read loop CA31.
March 1	Weather day. Heavy rains prevent access on dirt roads.
March 2	Read loops CA32 and CA33.
March 3	Read loops CA34 and CA35.
March 4	Read loops CA36 and CA37.
March 5	Pack equipment and ship to Honolulu.
March 6	Demobilize from Molokai, HI to Denver, CO.

Table 2-2. Daily Log of Field Activities (Gravity and Seismic Surveys)

Date (1990)	Activity
February 14	Mobilize from Denver, Colorado to Honolulu, Hawaii.
February 15	Mobilize from Honolulu to Molokai.
February 16	Read gravity stations B1, M1 through M12, and AP1.
February 17	Survey gravity stations B1, M1 through M5, and J1 through J7.
February 18	Survey gravity stations M6 through M18.
February 19	Read gravity stations M13 through M18, and J1 through J7.
February 20	Test seismic parameters and read spread S-1.
February 21	Read seismic spreads S-2 through S-5.
February 22	Read seismic spread S-6. Half-day of work. Waiting for additional charges.
February 23	No seismic work performed.
February 24	No seismic work performed.
February 25	Weather day. Heavy rains prevent access to site.
February 26	Read seismic spreads S-7 through S-10.
February 27	Read seismic spread S-11. Half-day of work.
February 28	Read seismic spreads S-12 through S-14.
March 1	Weather day. Heavy rains prevent access to site.
March 2	Read seismic spreads S-15 through S-17.
March 3	Demobilize from Molokai, HI to Denver, CO.

Map

Goes

Here

3.0 DATA PROCESSING

3.1 TDEM

The processing of the TDEM data consists of the following steps:

1. The raw data at each station were edited and averaged together in pairs.

2. Data pairs were edited for each base frequency and terminated at the point where excessive noise or minimum signal occurs.

3. Data pairs and base frequencies are averaged together to form one data set over the largest time range possible.

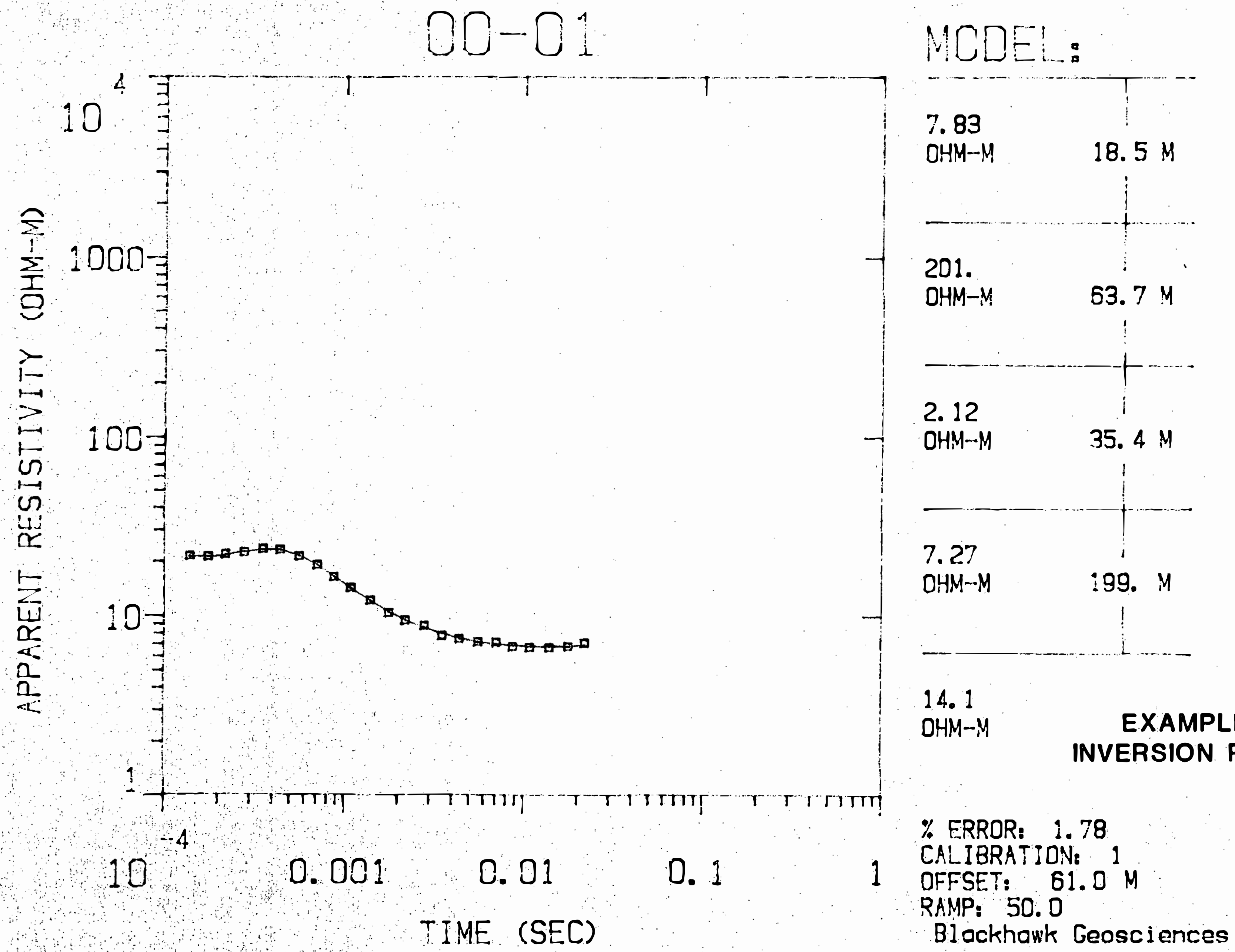
4. The data set produced in Step 3 is entered into an Automatic Ridge Regression Transient Inversion program.

The inversion program transforms the data into apparent resistivity values versus time. A starting geoelectric model (consisting of the number of layers, resistivities and thicknesses for each layer) is entered into the program. The inversion program then automatically adjusts the model parameters to obtain the best fit between the model and the field data. For all calculations a one-dimensional (horizontally layered) model is assumed.

The results of the transient inversion program from a typical sounding (sounding 1) are shown in Figures 3-1 and 3-2. Figure 3-1 shows the experimentally measured apparent resistivity data superimposed on the computed behavior (solid line) of subsurface resistivity layering that best matches the observed data. The resistivity layering of the best match is shown on the right. Figure 3-2 lists gate number, time, measured data, computed values, and errors for each time gate, as well as overall RMS error. The results of the 37 soundings are contained in the attachment to this report.

3.2 GRAVITY

Data reduction consisted of the following steps: The meter dial readings were converted to milligals using the meter factors for the LaCoste-Romberg Model G Gravimeter used for this survey. Earth tides were then calculated and added to the milligal values to obtain tide-corrected gravity. The instrument drift was then removed using station B-1 as a base station. The longest period between re-occupation of the base station for the survey was 3 hours 28 minutes. After all drift factors had been accounted for, latitude, free air effect, bouguer slab, and terrain corrections were calculated and applied to generate bouguer gravity. From bouguer gravity, lateral variations in subsurface density can be inferred.



EXAMPLE OF INVERSION RESULTS

FIGURE 3-1

EXAMPLE OF INVERSION DATA SHEET

FIGURE 3-2

00-01

MODEL: 5 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		67.1	220.0		
7.83	18.5	48.6	159.4	2.4	2.4
200.64	63.7	-15.1	-49.5	0.3	2.7
2.12	35.4	-50.5	-165.7	16.7	19.4
7.27	198.8	-249.3	-817.9	27.3	46.7
14.08					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.40E-04	2.13E+01	2.13E+01	-0.076	
2	1.77E-04	2.12E+01	2.12E+01	-0.131	
3	2.20E-04	2.19E+01	2.17E+01	0.708	
4	2.80E-04	2.25E+01	2.27E+01	-0.836	
5	3.55E-04	2.35E+01	2.34E+01	0.433	
6	4.43E-04	2.32E+01	2.31E+01	0.235	
7	5.64E-04	2.14E+01	2.15E+01	-0.730	
8	7.13E-04	1.91E+01	1.90E+01	0.602	
9	8.81E-04	1.64E+01	1.65E+01	-0.537	
10	1.10E-03	1.43E+01	1.42E+01	0.598	
11	1.41E-03	1.21E+01	1.20E+01	0.800	
12	1.78E-03	1.04E+01	1.05E+01	-1.328	
13	2.21E-03	9.45E+00	9.47E+00	-0.207	
14	2.83E-03	8.79E+00	8.58E+00	2.527	
15	3.55E-03	7.78E+00	7.96E+00	-2.260	
16	4.43E-03	7.45E+00	7.52E+00	-0.950	
17	5.64E-03	7.18E+00	7.17E+00	0.017	
18	7.13E-03	7.12E+00	6.94E+00	2.593	
19	8.81E-03	6.75E+00	6.80E+00	-0.754	
20	1.10E-02	6.68E+00	6.73E+00	-0.795	
21	1.41E-02	6.67E+00	6.72E+00	-0.696	
22	1.80E-02	6.78E+00	6.79E+00	-0.124	
23	2.22E-02	7.08E+00	6.92E+00	2.427	

R: 61. X: 0. Y: 61. DL: 122. REQ: 68. CF: 1.0000
CLHZ ARRAY, 23 DATA POINTS, RAMP: 50.0 MICROSEC, DATA: 00-01

RMS LOG ERROR: 7.67E-03, ANTILOG YIELDS 1.7810 %
LATE TIME PARAMETERS

* Blackhawk Geosciences *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.99							
P 2	-0.02	0.01						
P 3	0.03	0.00	0.88					
P 4	0.02	0.00	-0.07	0.93				
P 5	0.00	-0.01	-0.01	-0.04	0.86			
T 1	-0.02	-0.06	0.05	0.02	0.00	0.97		
T 2	0.00	0.02	0.02	0.01	0.00	-0.01	1.00	
T 3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

4.0 INTERPRETATION AND RESULTS

4.1 TDEM

The general procedures in the interpretation of TDEM soundings are discussed in BGI's December 1989 report entitled, "TDEM Survey, Western Portion of the Island of Molokai, State of Hawaii", and are not be repeated in this report.

The results of the TDEM survey are addressed in terms of the central aquifer area and western Molokai. Both areas include soundings from the present survey and the December 1989 survey.

4.1.1 Central Aquifer

The results of TDEM soundings are shown in Figures 4-1 and 4-2. Figure 4-1 is a contour map of the elevation of the top of the saline water. Also shown on the map is the hydrologic head calculated from the Ghyben-Herzberg principle. The depth below sea level of the top of the saline water interface is approximately equal to the thickness of the fresh to brackish water lens. It is expected that the basal ground water is mostly fresh northeast of the line from Kaunakakai through Kualapuu and mostly brackish southwest of this line.

From this contour map several features stand out. These are:

1. A central area at higher elevations where no saline waters were detected.

2. Thick zones of fresh water (> 700 ft) occurring close to the ocean along the north side of the island.

3. A rapid thinning of the fresh water lens along a northwest-southeast line running through the center of the map area.

4. Gradual thinning of the fresh/brackish water lens in the area of the Hoolehua Plain.

No saline water is detected in soundings CA16, CA25 and CA28 which are shown on Figure 4-1 to have resistive basements. The possible reasons for this are (i) the saline water is located far below sea level beyond the exploration limit of the TDEM system, or (ii) saline water has not migrated under this portion of the island due to dikes and/or intrusive bodies impeding the flow. In either case it is likely that dike-impounded water is present in this area. From the survey it is not possible to determine the elevation of fresh water above sea level.

Along the north side of the island from sounding CA29 at Meyers Lake to sounding CA18 north of Puu Anoano a thick fresh water lens is present. Because the proximity of this area to the ocean (less than 4,000 ft) a relatively thin lens would be expected due to drainage into the ocean. For this thickness to develop an impedance to ground water flow towards the ocean must exist. The most probable cause of this impedance is vertical dikes. The results of the gravity survey (Fig. 4-3) implies that an intrusive body is present at depth in this area. This makes it quite likely that numerous vertical dikes occur in the area.

The area of rapid thinning of the fresh to brackish ground water lens in the center of the map may be due to a decrease in the permeability of the lavas in this area. The area of rapid thinning generally parallels several volcanic vents. These vents include Puu Luahine, Kakalahale, the area northwest of the Kualapuu vent, and possibly Eleuweuewe and Puu Anoano. From soundings performed in the areas of volcanic vents, such as sounding 39 of the 1989 survey, and sounding CA14 of this survey, clay alteration of the surrounding volcanics is inferred. This alteration lowers the permeability of the volcanics which requires a larger drop in hydrologic head for ground water to move across the lower permeability area. The zones of lower permeability were not mapped directly by the TDEM soundings due to the relatively widely spaced soundings, but the distribution of the contours suggest a zone of lower permeability across this area.

The area of gradual thinning of the fresh to brackish water lens shows a fairly consistent trend. Soundings CA1 and CA2 of the present survey, however, show an anomalously thin brackish water lens. Sounding CA1 is adjacent to sounding 39 of the 1989 survey which does not detect saline water due to alteration of the volcanics. It is possible that this adjacent alteration is affecting sounding CA1 resulting in too low a value for the thickness of the brackish water lens. Because of this sounding CA1 was not used in deriving the contours of Figure 4-1. Sounding CA2 shows a 49 foot thick brackish water lens which is thinner than what is expected at that location. There is indication from nearby soundings that a trough of relatively thin lens may occur through this area.

4.1.2 <u>Western Molokai</u>

A total of eight soundings were made on western Molokai to better outline areas of relatively thick brackish water lenses which had been identified in the previous TDEM survey. These two areas are near Puu Nana and within Kakaaukuu Gulch. The results of the soundings are shown in Figures 4-4 through 4-6.

An east-west geoelectric section through the Puu Nana area is shown in Figure 4-4. Soundings CA19 and CA21 from the present survey were located adjacent to sounding CA20 of the previous survey, which showed a very thick brackish water lens. In CA21 the lens is approximately as thick as it is in sounding 20, while in CA19 the lens thins rapidly. In Figure 4-5 (a south to north cross-section) the lens thins rapidly in adjacent sounding CA20. To the north sounding CA36 shows altered volcanics below an elevation of approximately 200 ft. The alteration obscures the saline/brackish water interface, but it is unlikely that a large thickness of brackish water is present. The probable dimensions of where the lens is greater than 500 ft thick is 4,000 ft by 3,000 ft.

TOTAL VOL = 6×10^9 ft^3 @ 5% POROSITY, 2244 MG.

The results of the additional work to outline the thicker brackish water lens in Kakaaukuu Gulch is shown in Figure 4-6. The west-east cross-section shows the lens thinning rapidly on either side of sounding 31 of the 1989 survey. In Figure 4-5 soundings CA36 and CA37, approximately 3,000 ft south of sounding 31, show a clay-rich alteration of the volcanics at depth. As stated previously this alteration obscures the saline/brackish water interface. The thickness of the brackish water lens is probably not large in this area. The additional soundings in this area show the thicker than 300 ft brackish water lens to be relatively limited in extent.

4.1.3 <u>Correlation of Well Data and Soundings</u>

Several soundings were adjacent to or in the area of wells for which hydrologic data was available. Table 4-1 shows a comparison of the data from the two sources. The parameter measured in TDEM soundings is the thickness of the fresh to brackish water lens, while in the wells it is the hydrologic head of the ground water that is measured. Conversion of lens thickness to hydrologic head is made using the Ghyben-Herzberg principle, in which the thickness of a fresh water lens floating on sea water is approximately 40 times the hydrologic head of the fresh water.

Table 4-1 shows a good comparison between sounding CA10 and Well 0501-3. Soundings CA7 and CA17, however, show significant differences with nearby wells. Possible reasons for these differences are:

1. Surveying errors in determining the hydrologic head. NOT LIKELY! These are most likely caused by the drill hole not being exactly vertical. This causes the depth to ground water to be overestimated resulting in an underestimation of the hydrologic head of the ground water.

2. The locations are in the vicinity of rapid change of the thickness of the fresh water ground water wedge. Since TDEM soundings investigate a much larger volume than drill holes the sounding results reflect the average depth over a larger area.

Table 4-1. Comparison between sounding CA10 and well 0501-3

Sounding	Measured Lens Thickness	Computed Head	Well	Computed Lens Thickness	Measured Head	Ratio Well/ Sounding
7 ✓✓	832	20.8	0801	424	10.6	.51
10	88	2.2	0501-3	104	2.6	.85
17	610	15.3	0902-01	420	10.5	.69

4.1.4 Distortion of TDEM Soundings

In several of the TDEM soundings there was a relatively poor fit of interpreted model to portions of the data. Figure 4-7 is an example of such a sounding. In the time range 1 to 4 milliseconds the agreement between model and data is poor. The reasons for this are:

1. In certain geoelectric sections where highly resistive zones occur, it is difficult for the instrument to record the data over certain time ranges.

2. Lateral discontinuities (2-D effects), in this case a 1,200 ft cliff, make the data difficult to match utilizing 1-D modeling.

Although the stated overall error of fit of model to data is relatively high, most of the error is in a limited time range. Fortunately, the distortion of the curve does not extend into the time range that corresponds to the low resistivity zone of the saline water saturated volcanics. The primary interpreted parameter in this survey, i.e., the total depth to the saline water, is not expected to be severely affected by this type of curve distortion. The main parameter of the interpreted sounding that is affected is the magnitude of resistivity of the resistive volcanics which is probably overestimated. In addition, the resistivity of the saline water saturated volcanics may be somewhat underestimated.

Although the depth to the saline water saturated volcanics has a greater degree of uncertainty in distorted curves, these soundings are still useful in the overall interpretation of the area.

4.2 GRAVITY

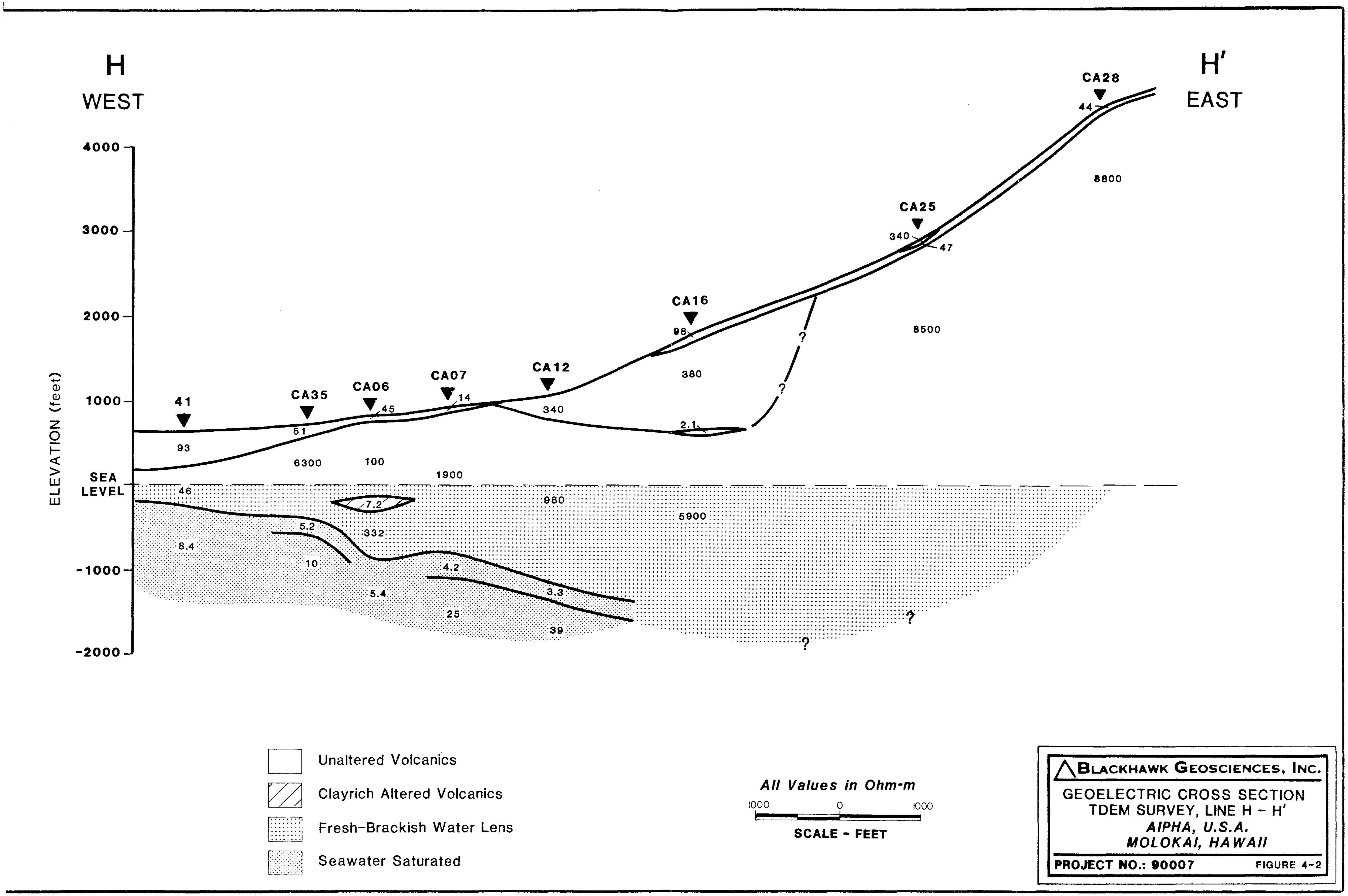
The plot of the bouger gravity anomaly is shown in Figure 4-3. A large regional gradient (>10 mgal) increasing from south to north is the main feature of the data. One likely interpretation of this gradient is a large deeply buried intrusive which is centered near the north shore of the island. Since the anomaly does not descend on the north it is difficult to place the exact position of the intrusive. The survey line does not show evidence of large intrusive bodies along the southern portion of the area covered by this line. This indicates that although small intrusive bodies with associated dikes may occur in the southern portion of the survey, the frequency of potential ground water impounding dikes should be much greater along the north side of the island.

It is difficult to outline small-scale features with one gravity line. From the present survey it is apparent that large-scale features associated with major intrusives are readily observable.

Map

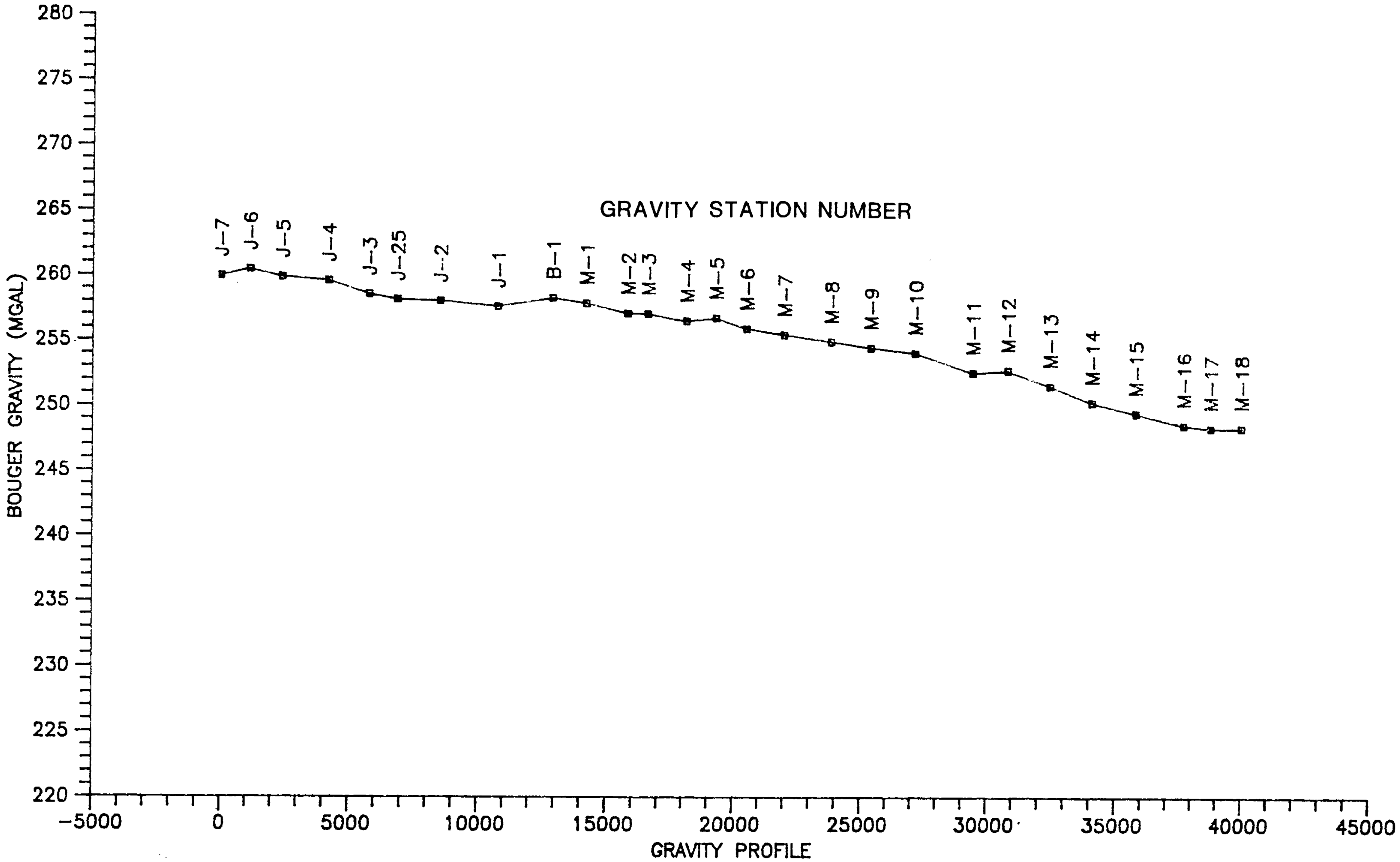
Goes

Here


H
WEST
H'
EAST
ELEVATION (feet)
4000
3000
2000
1000
SEA LEVEL
-1000
-2000
41
CA35
CA06
CA07
CA12
CA16
CA25
CA28
93
51
45
14
340
98
380
2.1
340
47
44
8800
8500
6300
100
1900
46
7.2
980
5900
5.2
332
8.4
10
4.2
5.4
3.3
25
39
Unaltered Volcanics
Clayrich Altered Volcanics
Fresh-Brackish Water Lens
Seawater Saturated
All Values in Ohm-m
1000
0
1000
SCALE - FEET
BLACKHAWK GEOSCIENCES, INC.
GEOELECTRIC CROSS SECTION
TDEM SURVEY, LINE H - H'
AIPHA, U.S.A.
MOLOKAI, HAWAII
PROJECT NO.: 90007
FIGURE 4-2

NW

SE



5000 0 5000

SCALE - FEET

BLACKHAWK GEOSCIENCES, INC.

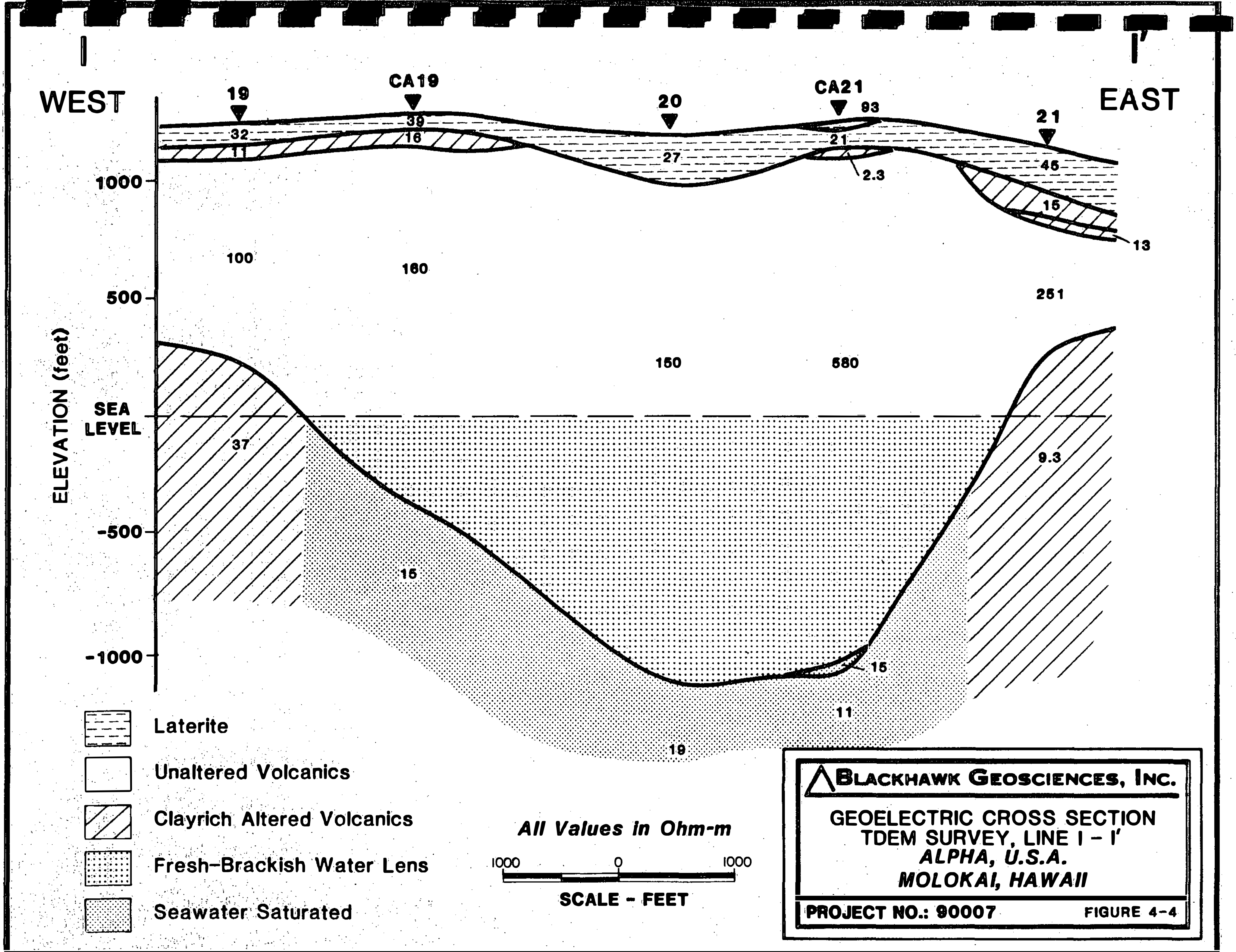
GRAVITY SURVEY

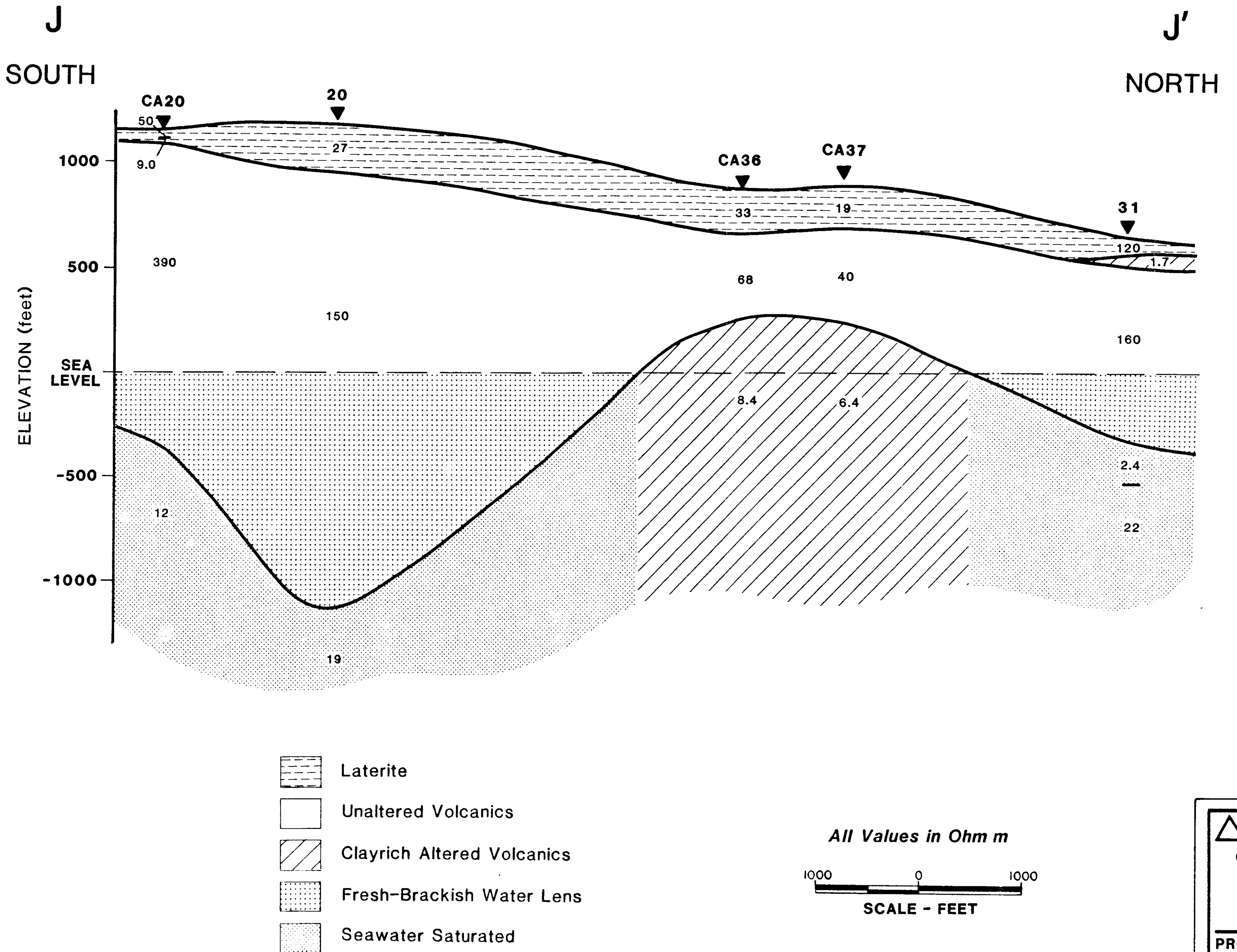
BOUGER GRAVITY PROFILE

ALPHA, U.S.A.

MOLOKAI, HAWAII

PROJECT NO.: 90007 FIGURE 4-3

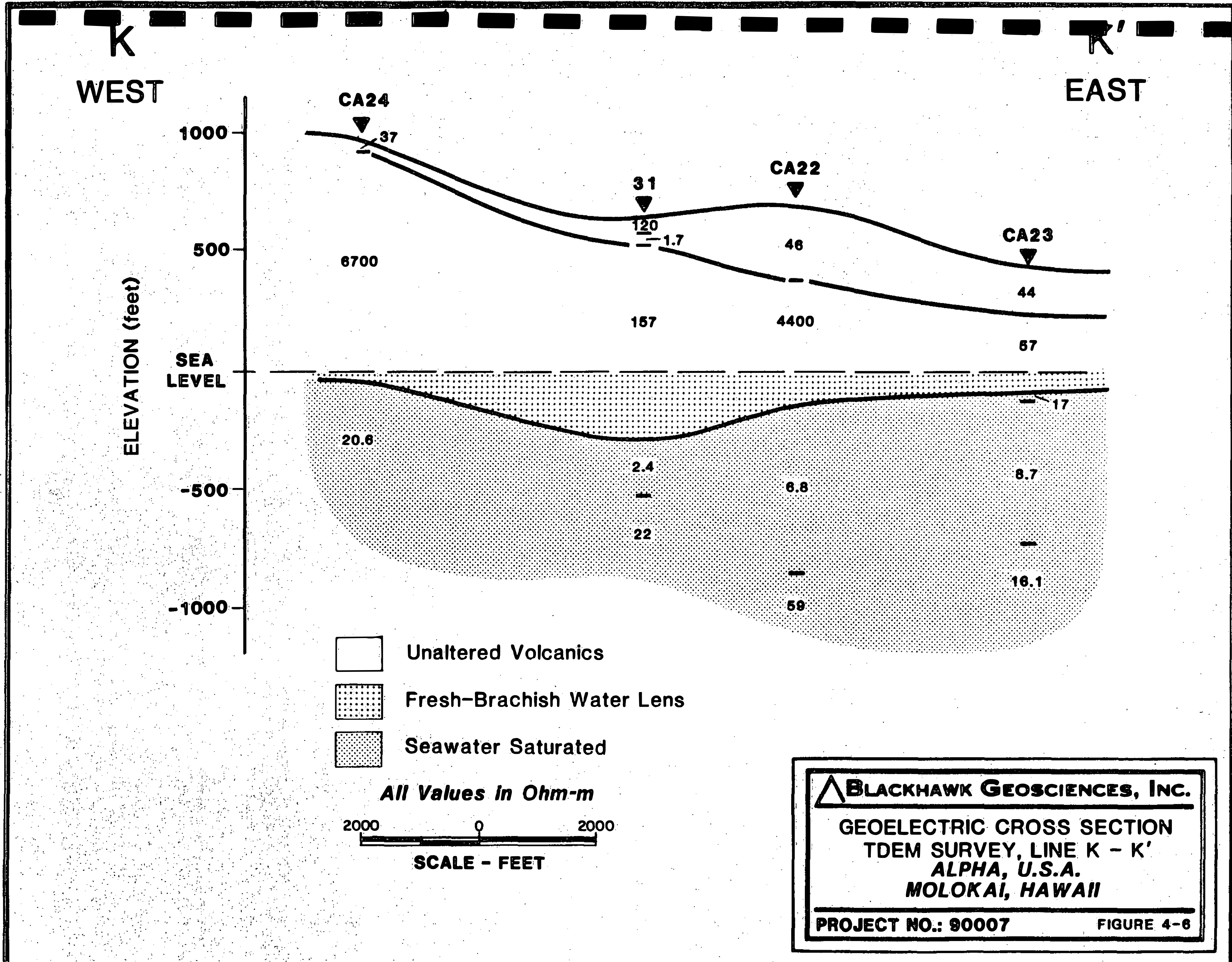

I
I'
WEST
EAST
19
CA19
20
CA21
93
21
32
39
16
11
27
21
2.3
45
15
13
1000
500
SEA LEVEL
-500
-1000
ELEVATION (feet)
100
160
251
150
580
37
9.3
15
15
11
19
Laterite
Unaltered Volcanics
Clayrich Altered Volcanics
Fresh-Brackish Water Lens
Seawater Saturated
All Values in Ohm-m
1000
0
1000
SCALE - FEET
BLACKHAWK GEOSCIENCES, INC.
GEOELECTRIC CROSS SECTION
TDEM SURVEY, LINE I - I'
ALPHA, U.S.A.
MOLOKAI, HAWAII
PROJECT NO.: 90007
FIGURE 4-4

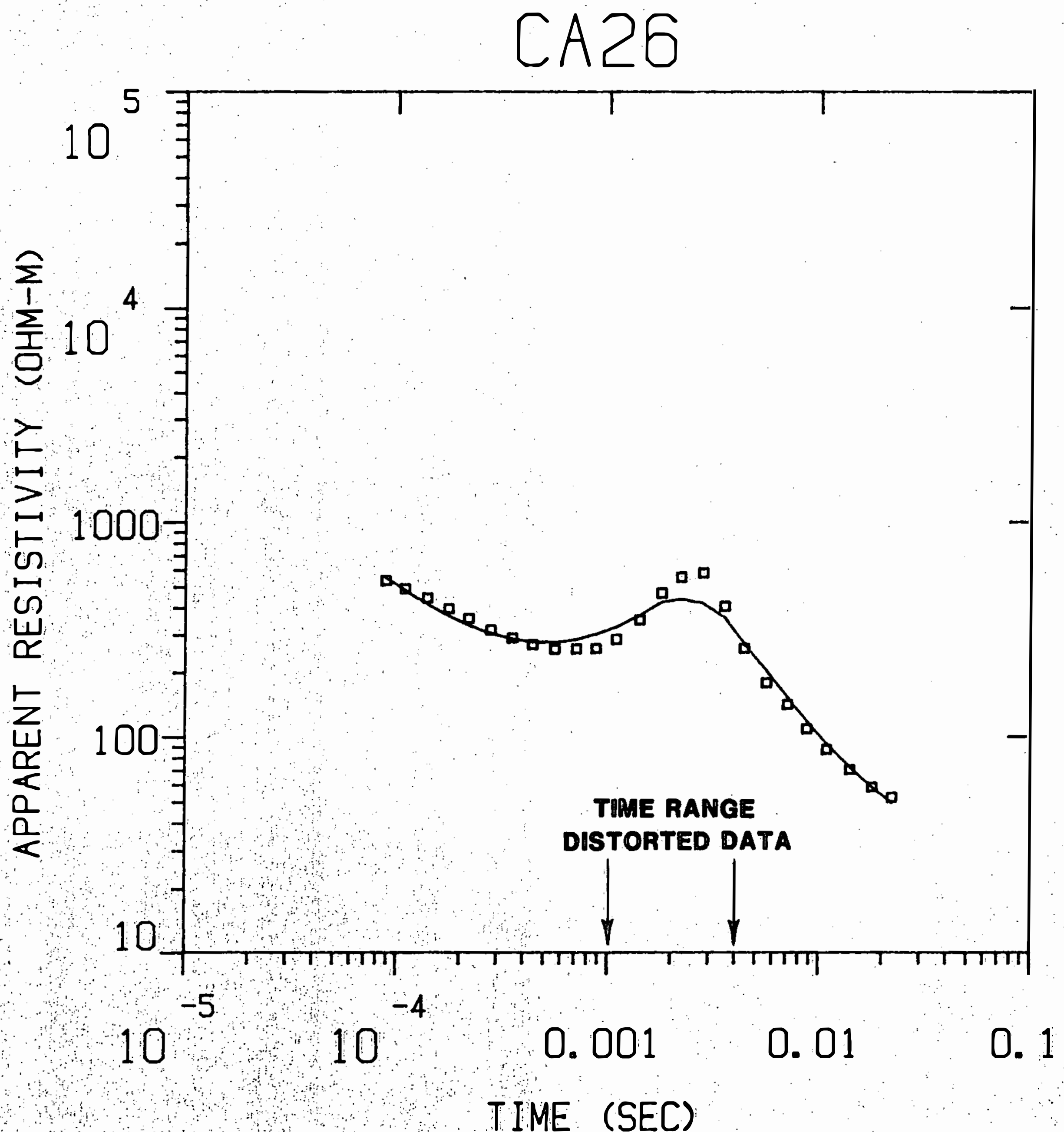


BLACKHAWK GEOSCIENCES, INC.

GEOELECTRIC CROSS SECTION
TDEM SURVEY, LINE J – J'
ALPHA, U.S.A.
MOLOKAI, HAWAII

PROJECT NO.: 90007 FIGURE 4-5


K
K'
WEST
EAST
CA24
31
CA22
CA23
1000
500
SEA LEVEL
-500
-1000
ELEVATION (feet)
37
120
1.7
46
6700
44
157
4400
57
17
20.6
2.4
6.8
8.7
22
16.1
59
Unaltered Volcanics
Fresh-Brachish Water Lens
Seawater Saturated
All Values in Ohm-m
2000
0
2000
SCALE - FEET
BLACKHAWK GEOSCIENCES, INC.
GEOELECTRIC CROSS SECTION
TDEM SURVEY, LINE K - K'
ALPHA, U.S.A.
MOLOKAI, HAWAII
PROJECT NO.: 90007
FIGURE 4-6



MODEL:

187 OHM-M	291 M
5555 OHM-M	489 M
1.30 OHM-M	46.7 M
57.3 OHM-M	

% ERROR: 18.0
CALIBRATION: 1
OFFSET: 150 M
RAMP: 200.0

Blackhawk Geosciences

FIGURE 4-7

5.0 SUMMARY AND CONCLUSIONS

The TDEM and gravity surveys over the central aquifer area of Molokai were effective in outlining the geohydrology of the island. The additional TDEM work performed on western Molokai was able to characterize the dimensions of areas underlain by relatively thick brackish water lenses. The main results of the survey are:

1. An area in which no saline waters were detected which probably is related to high-level dike impoundment.

2. An area along north Molokai adjacent to the coast in which a much thicker than expected fresh water lens is present. This is most likely related to dike impoundment.

3. A transition zone of rapid hydrologic head decline between the interpreted high-level dike-impounded water and the gradual decline in hydrologic head which occurs on the Hoolehua plain.

4. The relatively thick brackish water lenses of western Molokai at Puu Nana and in Kakaaukuu Gulch appear to be limited in areal extent.

6.0 SEISMIC REFRACTION SURVEY

6.1 INTRODUCTION

The seismic survey was performed in the area of Kamkaipo to map the distribution of consolidated and unconsolidated rock units. An estimation of the amenability of these rock units to excavation was made based on their seismic velocities. The survey was designed and interpreted based on the assumption that excavation would not go below 10 ft MSL.

6.2 LOGISTICS

The seismic refraction crew consisted of one BGI geophysicist and one local hire. The study area is shown on the base map (Fig. 2-1), and a larger scale map of the study area and seismic coverage is shown on Figure 6-1. Seventeen seismic refraction spreads were recorded during the survey. On February 25 and March 1 heavy rains made site access by four-wheel drive vehicle impossible.

A daily log of field activities is given in Table 2-2.

6.3 DATA ACQUISITION

The data collection system employed was the Geometrics Model ES-1225 12-channel signal enhancement seismograph.

The source type used for the survey was an 8-gauge blank shotgun shell. These shells were electrically fired with a Geometrics HVB-1 blaster. The charge size used for the survey varied from 1,000 to 1,500 grains of 4FG black powder, depending on geometry type.

Holes with a 4-inch diameter were bored in the ground using a post-hole digger. Hole depths averaged 18 to 24 inches. The shells were lowered into the hole and the hole was backfilled.

After the shell is in place and the seismic line is checked for excessive background noise, the blaster is armed and fired. At the instant of discharge (detonation) the blaster signals the seismograph to begin recording. After recording the data the seismograph displays the traces on a built-in CRT screen. If the record quality is good and shows a clear line of first breaks, the record is printed. The first arrivals from the refracted energy are then picked on the CRT screen using a moveable cursor and transcribed onto the plot of the seismic wavetrain (Fig. 6-2). The geometry used for the seismic spreads is shown in Figure 6-3.

6.4 DATA PROCESSING

The data was processed using the Seisview® seismic refraction processing software package.

The method used by Seisview to produce the layered model interpretation is recursive, based on the method of Mota (1959). It is applicable to horizontal and dipping layers in which the velocity of each layer is greater than all layers above it.

The first arrival times are plotted as a function of distance, and each first arrival time is assigned to a refracting layer. Seisview then calculates velocity and depth information using the slopes and intercept times from each refracting layer.

6.5 DATA INTERPRETATION

A map showing the locations of the seismic spreads is given in Figure 6-1. The velocity and depth information derived from the processed seismic spreads is displayed in cross-sectional form. These cross sections (profiles) show the depth to each refracting layer and the seismic velocity for each layer. The layer boundaries are interpolated in areas between spreads where there is no seismic coverage. These line profiles are given in Figures 6-4 through 6-7. Each profile uses 1" = 100 ft for horizontal scale, and 1" = 10 ft for vertical scale. Elevations for the profiles were inferred from the topographic map. From these rock profiles, a contour map showing elevation of top to volcanic rocks was produced at a scale of 1" = 500 ft (Fig. 6-8).

The seismic data showed that the subsurface consisted of two basic units. The first unit is expected to be unconsolidated clays and beach sands. The velocity of unconsolidated sediments varies from 500 ft/sec for loose, dry sediments to over 5,000 ft/sec for sediments below the water table. The second unit is expected to be volcanics with velocities greater than 6,000 ft/sec.

<u>Line 1</u> (Fig. 6-4)

At the far north end of Line 1, beneath spreads 2 and 8, there are valleys eroded in the volcanics separated by a ridge of volcanics at spread 8. Although these valleys are well below the -10 ft MSL excavation depth, their width appears to be only about 500 ft, and their extent perpendicular to the plane of the cross-sectional profile is unknown. Beginning at spread 4 and continuing to the southern end of the line at spread 3, the top of the volcanics appear to lie near to or above -10 ft MSL in elevation. Ridges in the volcanics at spreads 9 and 3 occur at elevations of 3 and 5 ft MSL, respectively, and the northern half of spread 10 is the only area along line 1 where the seismic refraction data show the top of the volcanics to lie below the -10 ft MSL elevation of desired excavation.

Line 2 (Fig. 6-5)

The top of volcanics lies below -10 ft MSL near the west end of Line 2 (spread 13) and rise to a maximum of -3 ft MSL at the east end of spread 5. At spread 11 the volcanics are at an elevation of -6 ft MSL at the west end, cross -10 ft MSL near the center of the spread, and have an elevation of -17 ft MSL at the east end of the spread.

Line 3 (Fig. 6-6)

The top of the volcanics are relatively flat along spreads 16 and 17. The maximum elevation of volcanics is 7 ft MSL and the minimum elevation is 2 ft MSL.

Line 4 (Fig. 6-7)

Line 4 shows the volcanics to lie between 4 ft MSL and 10 ft MSL along the line. Line 4 is similar to Line 3 both in elevation of volcanics and the relative flatness of the top of the volcanics.

The rippability of rock as related to its seismic wave velocity for a D-9 or equivalent bulldozer is shown in Figure 6-9 which is published by Caterpillar Inc. From the figure basalts with velocities of 8,600 ft/sec or greater are non-rippable. The spreads which showed velocities greater than 8,600 ft/sec lying above -10 ft MSL are spreads 4, 6 and 10 along Line 1, and spread 17 on Line 3. These non-rippable areas are shown on the profiles.

6.6 DISCUSSION

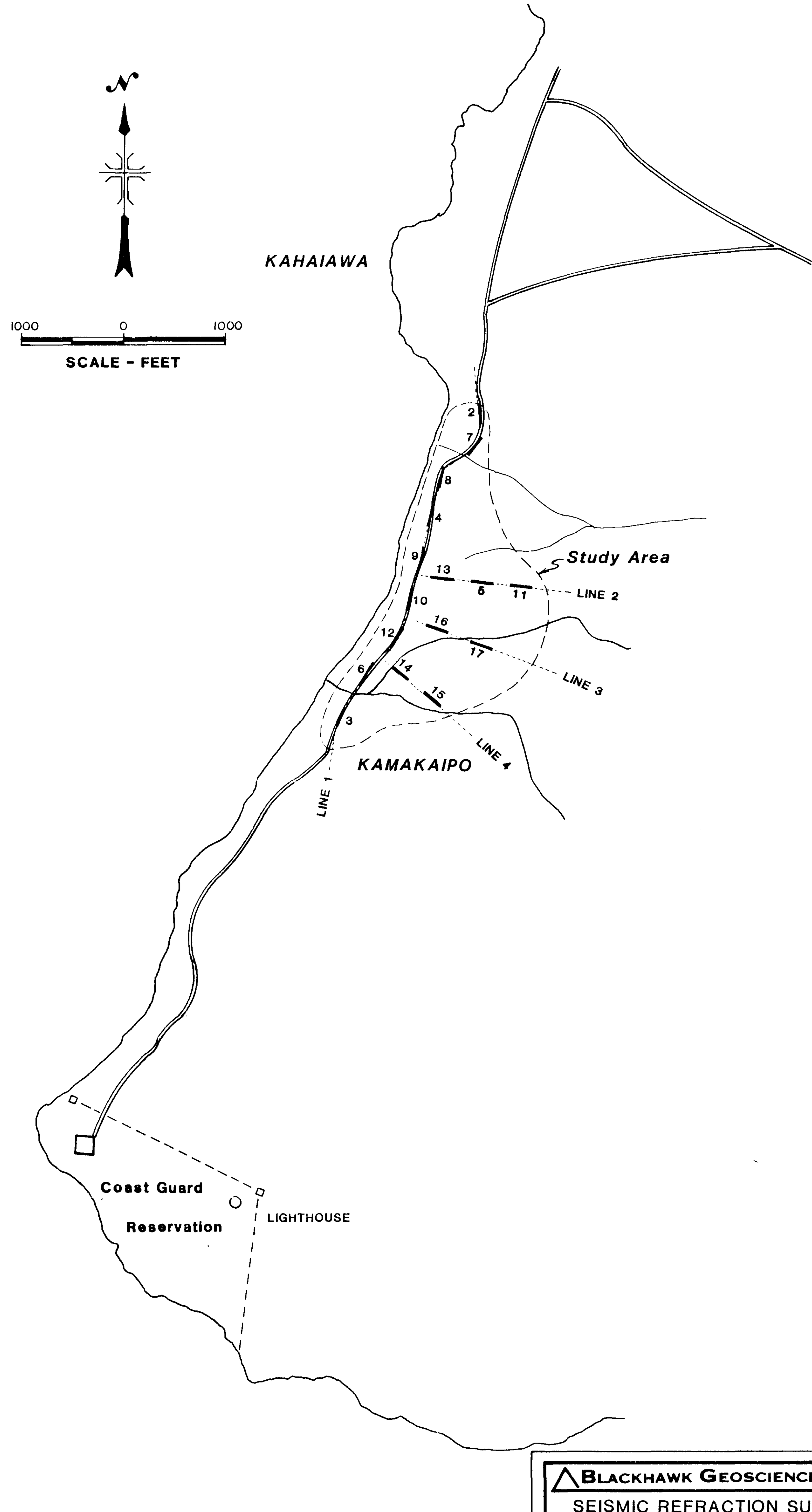
For use of the seismic velocity profiles in predicting ease of excavation we make the following comments:

1. The high hydraulic permeability of the volcanics may make it difficult to dewater an excavation by enclosement with a sheet pile wall, and pumping, so that rippers may not be useable below sea level. Only the material with a velocity less than 6,000 ft/sec (soils) can likely be removed by excavators, and all volcanic rocks likely will require blasting. Figure 6-10 shows contours of thickness of volcanic rocks within the study area that can likely be removed by excavators. This figure assumes that depth of excavation is -10 MSL.

2. In the event dewatering of the excavation is feasible, and tractors with rippers can be used, the charts of the Caterpillar Company shown on Figure 6-9 can be used to estimate areas with volcanic rocks above -10 MSL that can be ripped. A contour map of the elevation of the top of volcanics is presented in Figure 6-8. This map shows the valleys and ridge at the north end of the survey. To the south of spread 8 the top of the volcanics generally increases towards the south end of the survey.

<u>Reference</u>

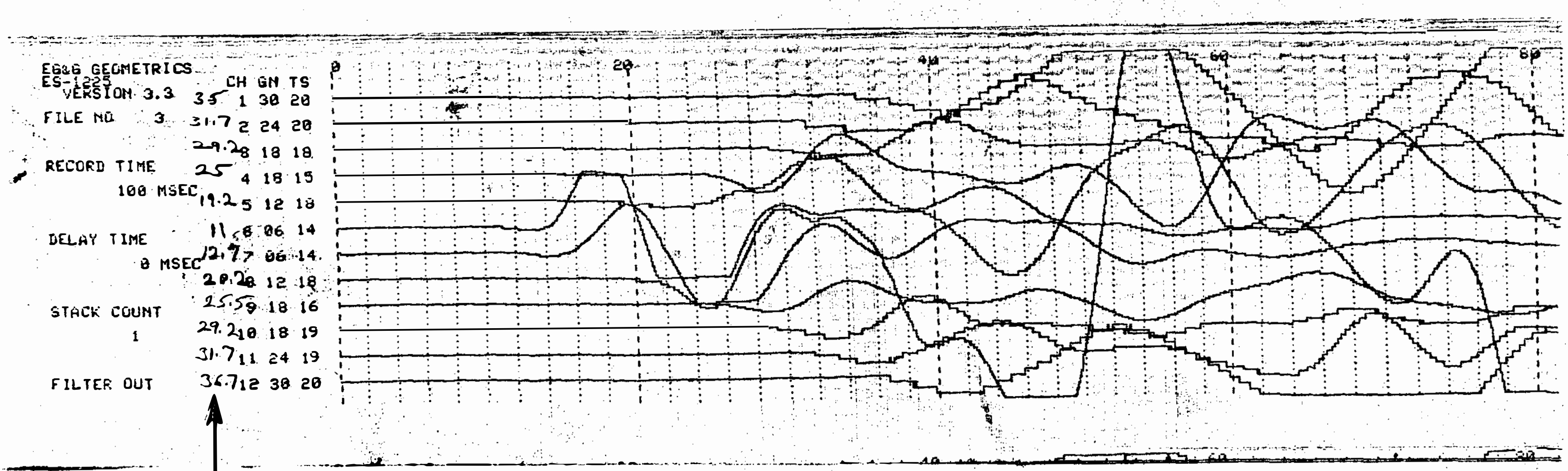
Mota, Lindoner, 1959. Determination of dips and depth of geologic layers by the seismic refraction method: Geophysics, V 19, No 2, p. 242-254.



BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY
GENERAL LOCATION MAP
ALPHA, U.S.A.
MOLOKAI, HAWAII

PROJECT NO.: 90007 FIGURE 6-1

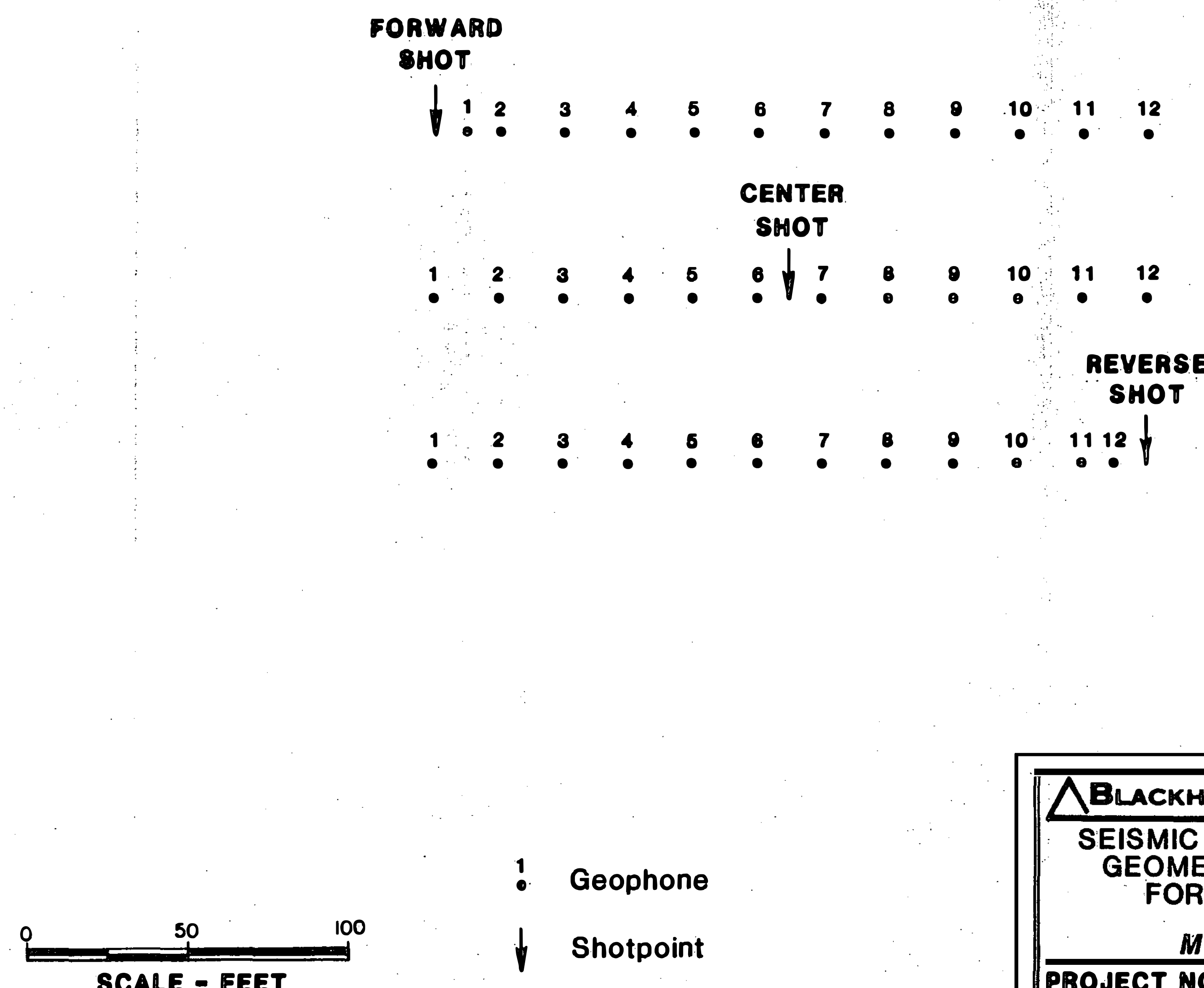


FIRST ARRIVAL TIMES

BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY
SEISMIC DATA RECORD
ALPHA, U.S.A.
MOLOKAI, HAWAII

PROJECT NO.: 90007 **FIGURE 6-2**



BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY GEOMETRY CONFIGURATION FOR SEISMIC SPREADS

ALPHA, U.S.A.

MOLOKAI, HAWAII

PROJECT NO.: 90007

FIGURE 6-3

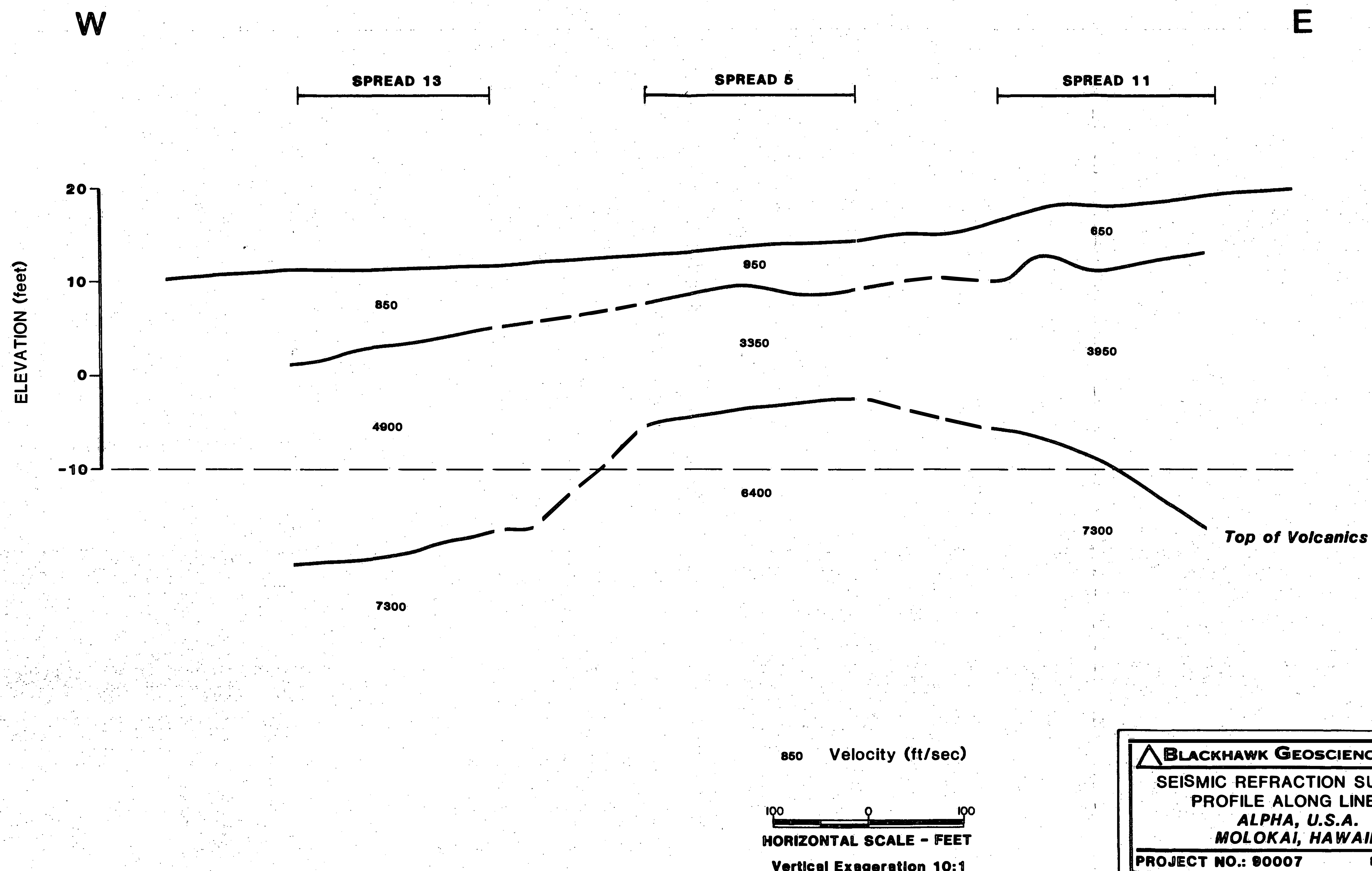
SEISMIC REFRACTION SURVEY
PROFILE ALONG LINE 1
ALPHA, U.S.A.
MOLOKAI, HAWAII

PROJECT NO.: 90007 FIGURE 6-4

Map

Goes

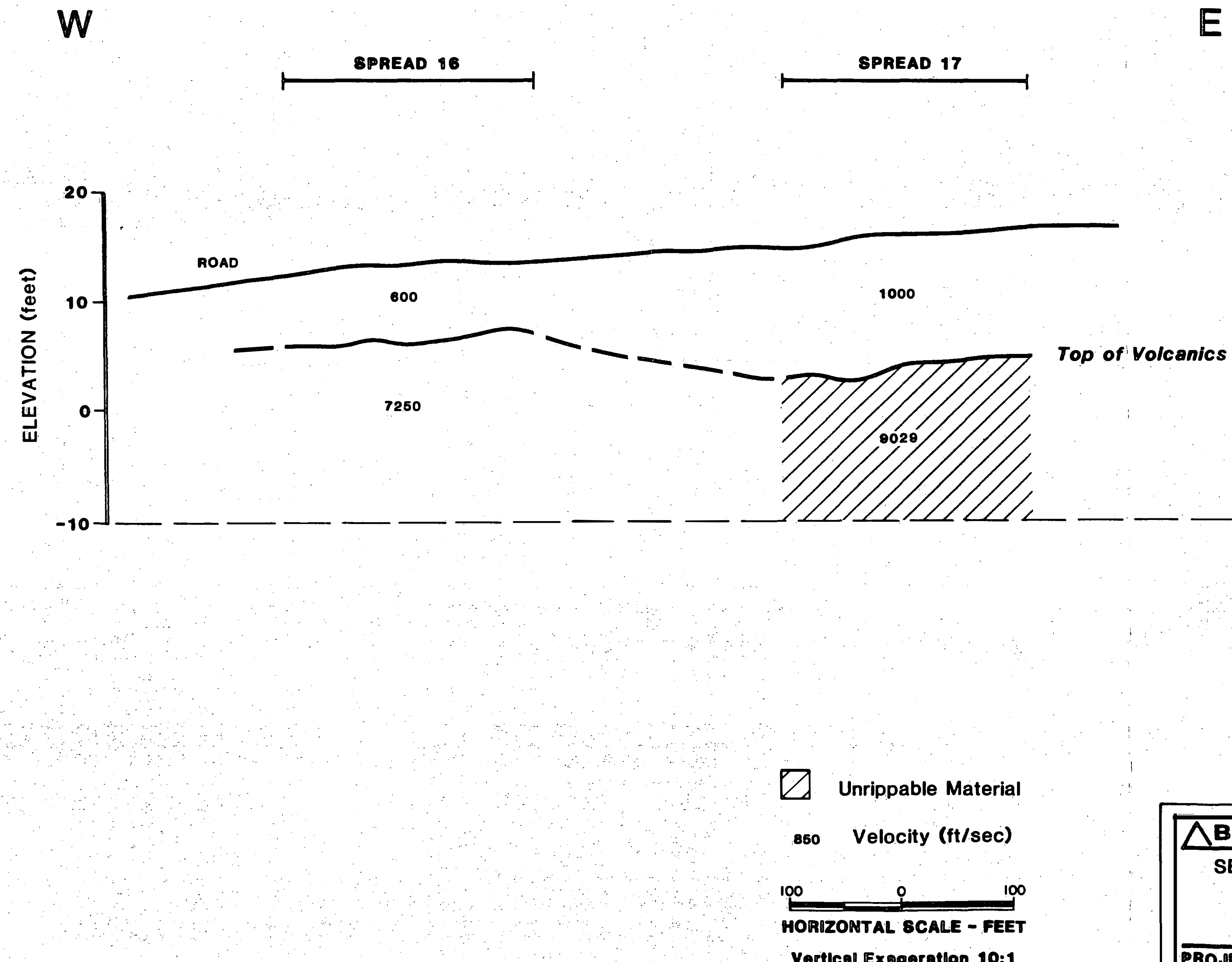
Here



BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY
PROFILE ALONG LINE 2
ALPHA, U.S.A.
MOLOKAI, HAWAII

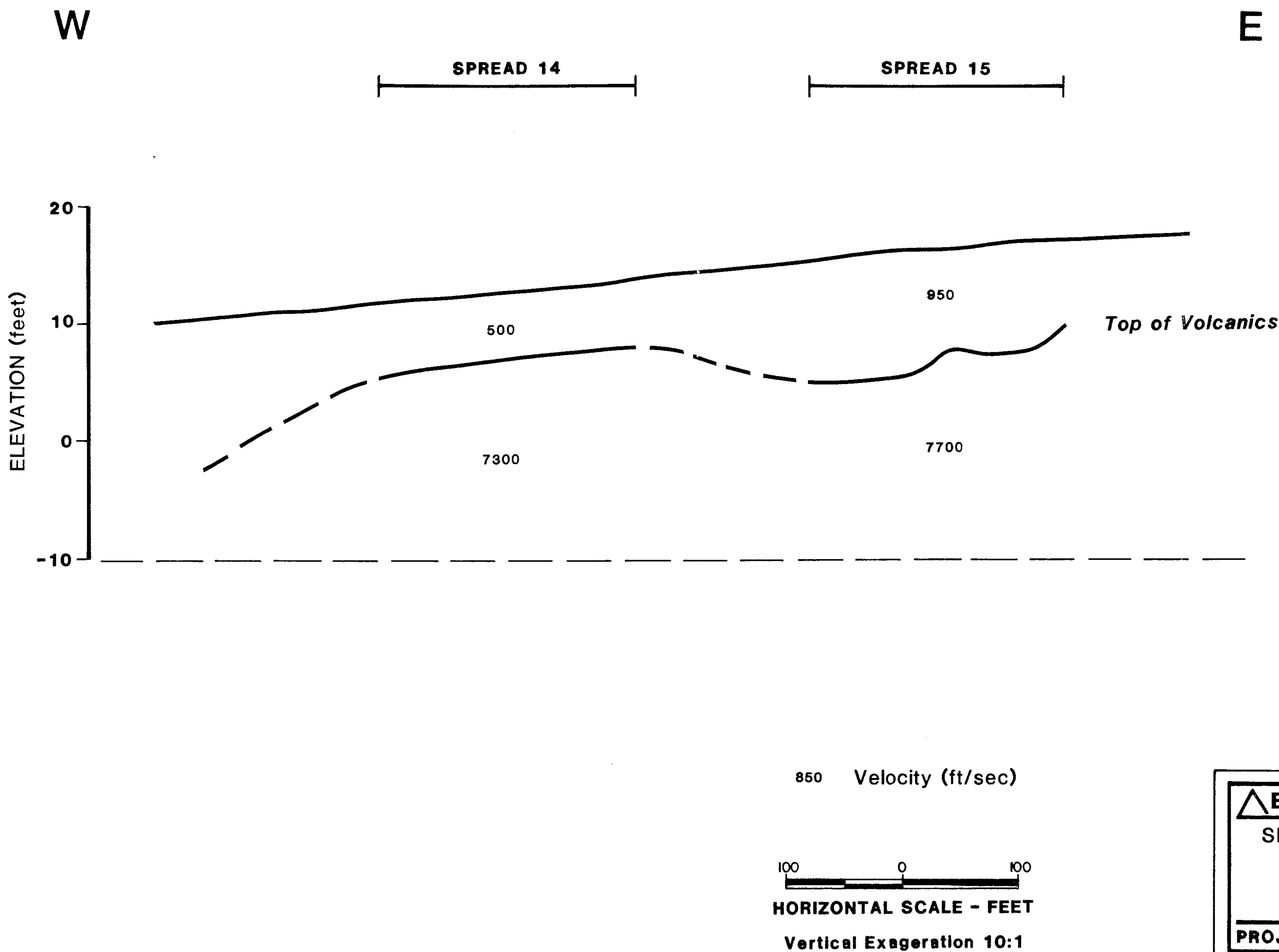
PROJECT NO.: 90007 FIGURE 6-5



BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY
PROFILE ALONG LINE 3
ALPHA, U.S.A.
MOLOKAI, HAWAII

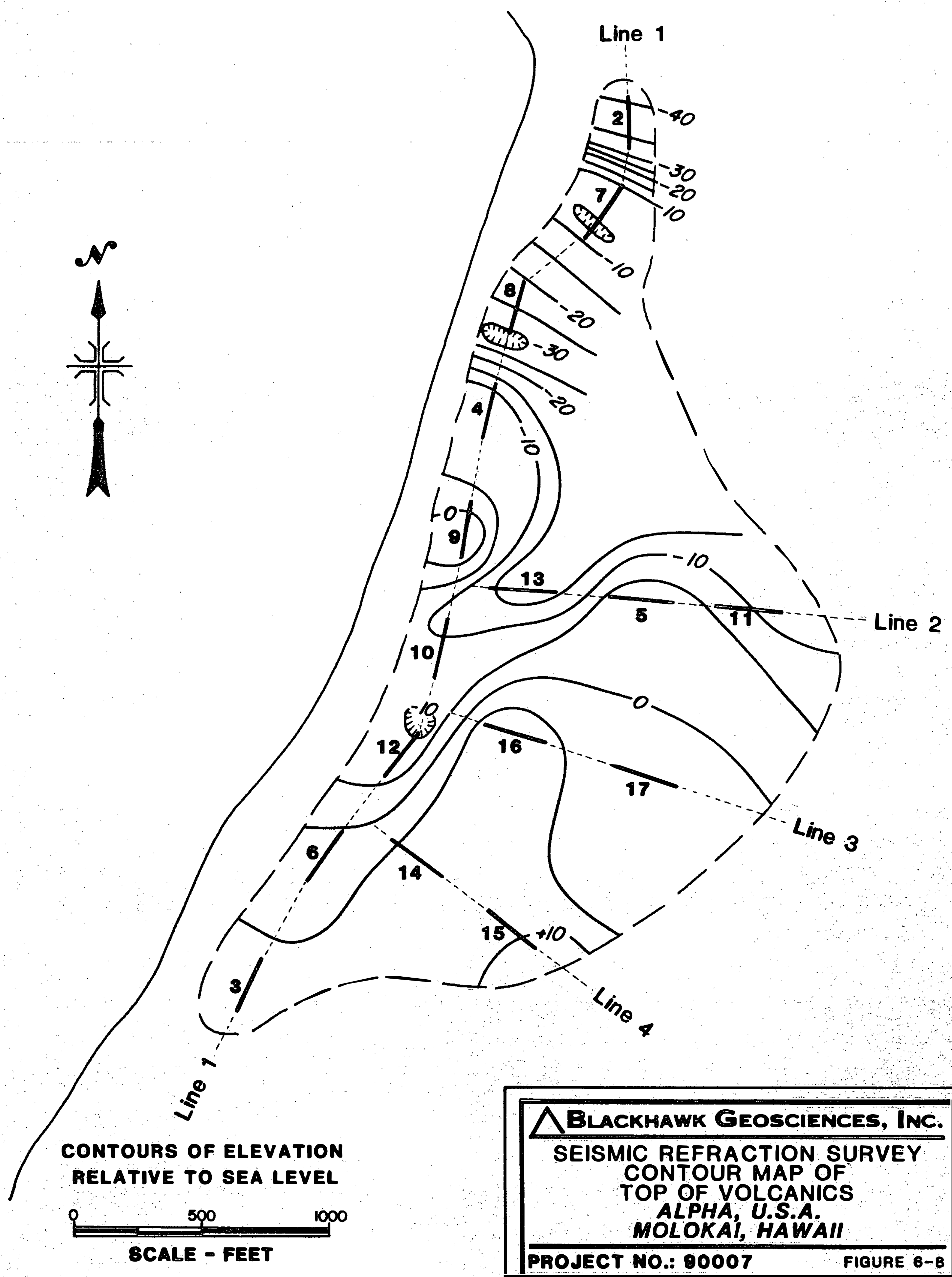
PROJECT NO.: 90007 FIGURE 6-6



BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY
PROFILE ALONG LINE 4
ALPHA, U.S.A.
MOLOKAI, HAWAII

PROJECT NO.: 90007 FIGURE 6-7

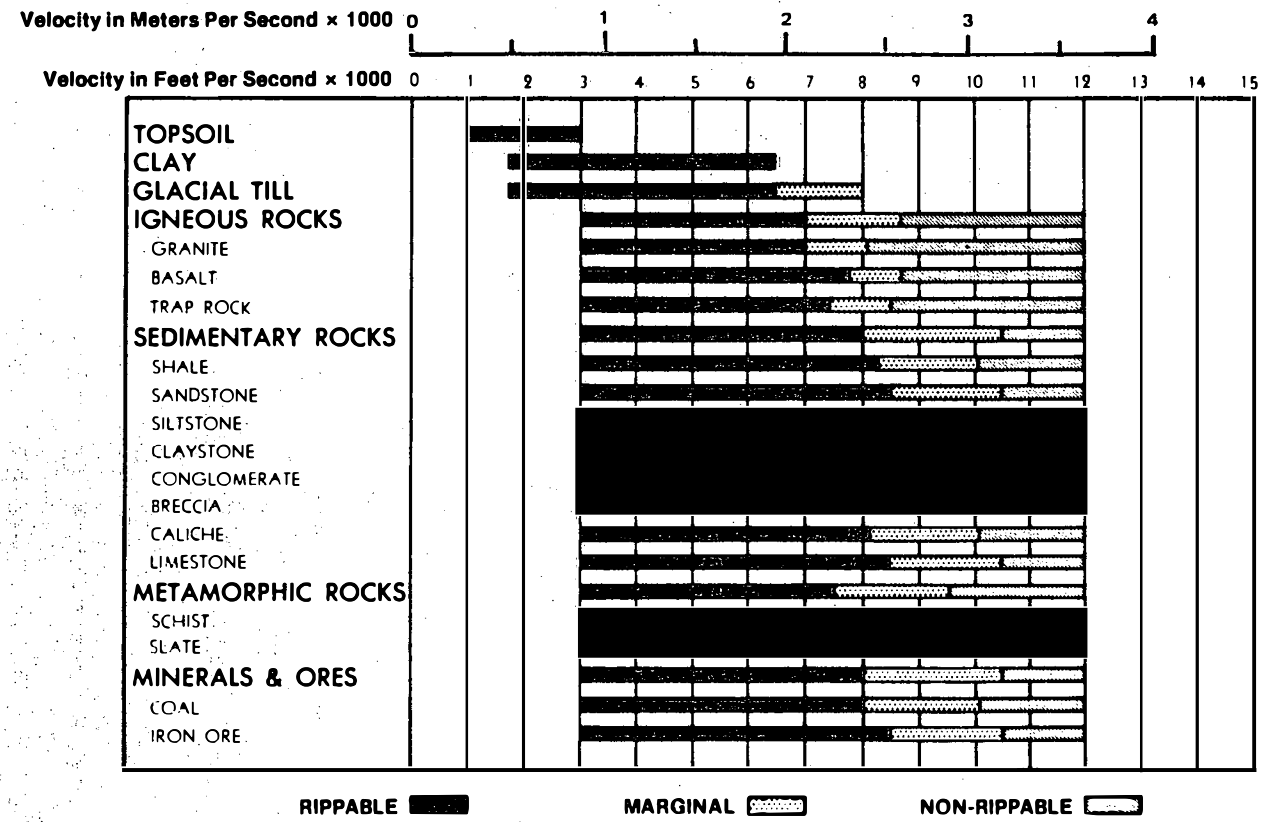


BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY
CONTOUR MAP OF
TOP OF VOLCANICS
ALPHA, U.S.A.
MOLOKAI, HAWAII

PROJECT NO.: 90007 **FIGURE 6-8**

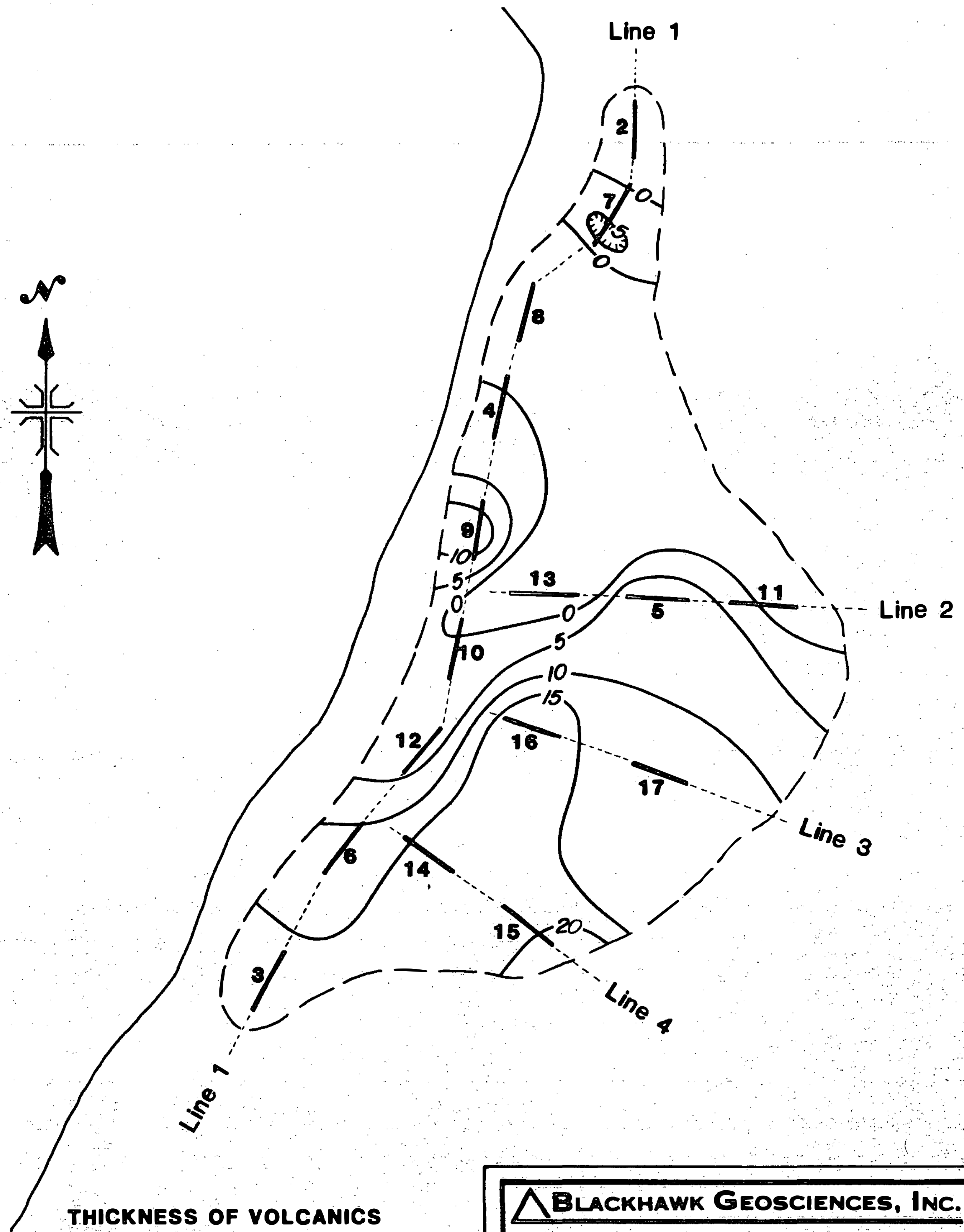
TYPICAL CHART OF RIPPER PERFORMANCE AS RELATED TO SEISMIC WAVE VELOCITIES



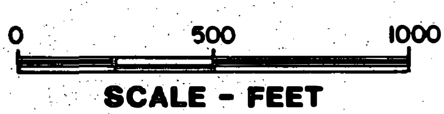
BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY
RIPPABILITY CHART
ALPHA, U.S.A.
MOLOKAI, HAWAII

PROJECT NO.: 90007 FIGURE 6-9



THICKNESS OF VOLCANICS
ABOVE -10 ft. M.S.L.



BLACKHAWK GEOSCIENCES, INC.

SEISMIC REFRACTION SURVEY
THICKNESS OF VOLCANICS
ALPHA, U.S.A.
MOLOKAI, HAWAII

PROJECT NO.: 90007 FIGURE 6-10